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# Some arguments in support of the association of PSR B 1706−44 with the supernova remnant G 343.1−2.3

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**Abstract.** We present some arguments in support of the association of the pulsar PSR B 1706−44 with the supernova remnant G 343.1−2.3, based on the idea that these objects could be the result of a supernova explosion within a mushroom-like cavity (created by the supernova progenitor wind breaking out of the parent molecular cloud). We suggest that in addition to the known bright "half" of G 343.1−2.3 there should exist a more extended and weaker component, such that the actual shape of G 343.1−2.3 is similar to that of the well-known SNR VRO 42.05.01. We have found such a component in archival radio data.

## 1. Introduction

PSR B 1706−44 (Johnston et al. 1992) is superposed on the outer edge of an incomplete arc of radio emission discovered by McAdam, Osborne, & Parkinson (1993). McAdam et al. interpreted the arc as a shell-type supernova remnant (SNR), named G 343.1−2.3, and suggested that it is physically associated with PSR B 1706−44. This suggestion was questioned by Frail, Goss, & Whiteoak (1994) and Nicastro, Johnston, & Koribalski (1996) on three bases: Gaensler & Johnston's (1995) statistical study, which suggests that young ($<$ 25 000 yr) pulsars cannot overrun their parent SNR shells (the spin-down age of PSR B 1706−44 is $\simeq$ 17 500 yr); an inconsistency between the implied and measured (scintillation) transverse velocities of the pulsar; and the absence of any apparent interaction between the pulsar and the SNR's "shell". In this paper we show how the existing observational data on PSR B 1706−44 and G 343.1−2.3 can be interpreted in favor of their physical association (cf. Dodson et al. 2001).

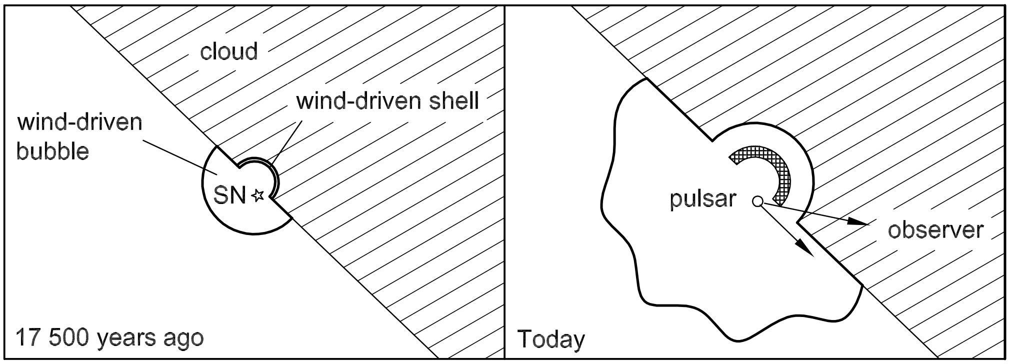


Figure 1. Schematic of the proposed origin of G 343.1−2.3

## 2. The supernova remnant G 343.1−2.3

### 2.1. Observational data

The 843 MHz image of G 343.1−2.3 by McAdam et al. (1993) shows a well-defined arc (a half-ellipse) of radio emission of maximum extent about $40'$. A VLA image of the SNR obtained by Frail et al. (1994) shows the existence of weak, diffuse emission both inside and outside the bright arc. This emission fills a region similar to and about two times more extended than the bright arc (Dodson et al. 2001; see also Duncan et al. 1995 and Fig. 2).

### 2.2. The origin of the pulsar/SNR system

We suggest that the SNR G 343.1−2.3 is the result of an off-centered cavity supernova (SN) explosion. Fig. 1 schematically depicts a scenario for its origin. A massive star (the progenitor of the SN) ends its evolution within a mushroom-like cavity formed by the SN progenitor wind breaking out of the parent molecular cloud and expanding into an intercloud medium of much less density. The proper motion of the progenitor star results in a considerable offset of the SN explosion site from the geometrical center of the semi-spherical cavity created inside the cloud; we suggest that the SN exploded outside the cloud. The subsequent interaction of the SN blast wave with the reprocessed ambient medium determines the structure of the resulting SNR (e.g. Franco et al. 1991), which acquires a form reminiscent of the well-known SNR VRO 42.05.01. We speculate that the wind-blown cavity formed inside the cloud was surrounded by a shell of mass less than some critical value (for spherically-symmetric shells this value is about 50 times the mass of the SN ejecta; e.g. Franco et al. 1991), so that the SN blast wave was able to overrun the shell to propagate further into the unperturbed gas of the cloud, leaving behind the reaccelerated and gradually broadening turbulent shell. We suggest that the bright arc of G 343.1−2.3 corresponds to the shocked former wind-driven shell and that the diffuse radio emission comes from the "half" of the SN blast wave propagating into the molecular cloud (see Fig. 1). These two components of the SNR form the "stem" of the "mushroom". We expect that a more extended component of the SNR (the "cap" of the "mushroom") should exist to the southeast of the bright arc, which corresponds to the

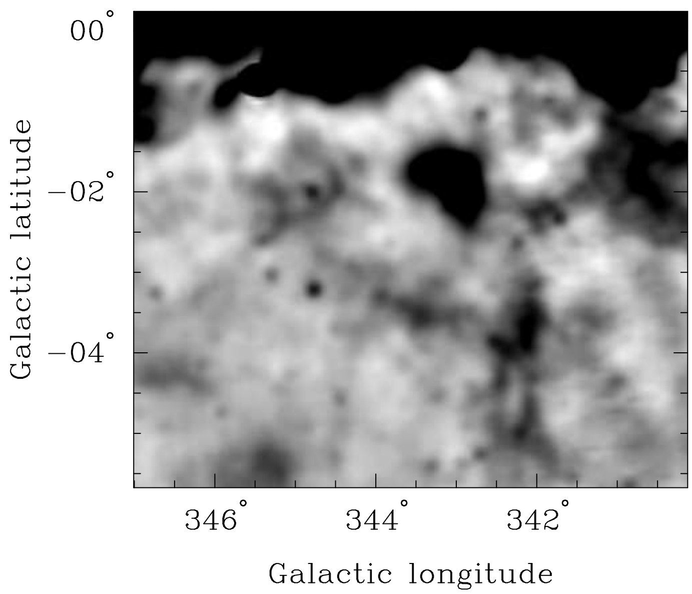


Figure 2. 2.4 GHz image of G 343.1−2.3 (Duncan et al. 1995)

"half" of the SN blast wave expanding in the intercloud medium. It is curious that the 2.4 GHz Parkes Survey (Duncan et al. 1995) reveals such a structure (Fig. 2). Although this structure could be a foreground or background object, its location in the "proper" place and its symmetry with respect to the bright arc of G 343.1−2.3 suggests that it could be physically related to this SNR.

## 3. Reliability of the pulsar/SNR association

### 3.1. On the statistical argument against the association

Although it is now clear that PSR B 1706−44 is located (at least in projection) well within the SNR G 343.1−2.3 (Dodson et al. 2001), we note here that Gaensler & Johnston (1995) did not consider two very important effects: modification of the ambient medium by the ionizing emission and stellar wind of massive stars (the progenitors of most SNe), and the proper motion of SN progenitor stars (Gvaramadze 2000, 2002). Taking into account these two effects allows it to be shown that even a young pulsar moving with a moderate velocity ($\simeq 200\,\mathrm{km\,s^{-1}}$) is able to escape the SNR's shell, provided it was born not far from the edge of the wind-driven bubble. Alternatively, the apparent location of a pulsar on the edge of SNR's shell could be due simply to the effect of projection in non-spherically-symmetric SNRs (see Fig. 1).

### 3.2. On the pulsar velocity

The implied pulsar transverse velocity, i.e. the velocity inferred from the angular displacement of PSR B 1706−44 from the geometrical center of the (bright) arc, is $V_{\mathrm{imp}} \simeq 700\,\theta_{20} D_{2.1} \tau_{17.5}^{-1}\,\mathrm{km\,s^{-1}}$, where $\theta_{20}$ is the angular displacement in units of $20''$, $D_{2.1}$ is the distance to the pulsar in units of 2.1 kpc, and $\tau_{17.5}$ is the

spin-down age of the pulsar in units of 17.5 kyr. Nicastro et al. (1996) compared this estimate to one derived from scintillation measurements, finding the latter anomalously low ($\simeq 0.05 V_{\rm imp}$). The inconsistency was used by Nicastro et al. to suggest that the pulsar did not originate from the apparent center of SNR, and that the pulsar and SNR are not associated. We agree with their first suggestion (see §2.2) and therefore believe that the implied velocity can be reduced. On the other hand we have found (Bock & Gvaramadze, in preparation) that if the turbulent material of the reaccelerated former wind-driven shell (the bright arc of SNR) is responsible for nearly all the scattering of PSR B 1706−44, then the pulsar moves in the same direction and with nearly the same (transverse) velocity as does the part of the bright arc projected on the pulsar (cf. Gvaramadze 2001). If so, one can use the non-detection of soft X-ray emission from the SNR (Becker, Brazier, & Trümper 1995) to show that the pulsar transverse velocity should indeed be less than $V_{\rm imp}$, though it can be much larger than that calculated by Nicastro et al. (1996). We also expect that the pulsar proper motion is from the northeast to the southwest; this should be tested observationally.

### 3.3. On the absence of interaction between the pulsar and the SNR

The absence of any morphological signature of an interaction between PSR B 1706−44 and G 343.1−2.3, despite the apparent proximity of the pulsar to the bright arc of the SNR, can easily be explained if the SN indeed exploded within a mushroom-like wind-driven cavity, as discussed above.

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